Atlas Tech Note No. 7
Galvanic Corrosion

What Galvanic Corrosion Is

Galvanic corrosion is a localised mechanism by which metals can be preferentially corroded. This form of corrosion has the potential to attack junctions of metals, or regions where one construction metal contacts another. Frequently this condition arises because different metals are more easily fabricated into certain forms; an example might be a door frame manufactured from aluminium extrusions (aluminium extrudes extremely well into architectural sections), but with a door handle fabricated from stainless steel tube to exploit its higher strength and abrasion resistance. Galvanic corrosion is well known to most designers, specifiers and fabricators, but often the only rule in force is "don't mix metals".

What Conditions Are Needed

For galvanic corrosion to occur there are three conditions which must be met ... and some qualifications to these conditions as well:

Condition 1. Metals must be far apart on the galvanic series

The galvanic or electrochemical series ranks metals according to their potential, generally measured with reference to the Standard Calomel Electrode (S.C.E.). The results are often viewed as a chart similar to that on the third page of this Atlas Tech Note. This chart says that the "anodic" or "less noble" metals at the negative end of the series – at the right of this diagram, such as magnesium, zinc and aluminium – are more likely to be attacked than those at the “cathodic" or "noble" end of the series such as gold and graphite. The critical point is the difference in potential of the two materials being considered as a joined pair. A difference of hundreds of millivolts is likely to result in galvanic corrosion, but only a few tens of millivolts is unlikely to be a problem. A rule of thumb is that differences over about 200mV (0.2 Volts) suggest galvanic corrosion could be a concern.

Although stainless steels are rightly considered to be towards the noble end of the spectrum, other materials are even more noble. Note particularly the position of graphite – galvanic coupling between stainless steels and graphite should be avoided. Graphite-containing gaskets, seals, packing and lubricants should not be used in contact with stainless steels in contact with sea water. Carbon black in rubber is a common source of this graphite; significant variations in the galvanic effect occur due to the use of different rubbers containing various amounts and types of carbon black filler.

Condition 2. The metals must be in electrical contact

The two different metals must be in electrical contact with each other. This is of course very common. The two metals can be bolted, welded or clamped together, or even just resting against each other.

Condition 3. The metal junction must be bridged by an electrolyte

An electrolyte is simply an electrically conducting fluid. Almost any fluid falls into this category, with distilled water as an exception. Even rain water is likely to become sufficiently conducting after contact with common environmental contaminants. If the conductivity of the liquid is high (a common example is sea water) the galvanic corrosion of the less noble metal will be spread over a larger area; in low conductivity liquids the corrosion will be localised to the part of the less noble metal near to the junction. Different ions in the fluid also behave differently; chloride ions (such as in sea water) are particularly aggressive while hydroxide ions are often passive. The concentration of ions is relevant, but the effect can be changed due to dissolution of ions from the corroding metal and to variable solubility of oxygen, among other effects.

The Area Effect

The relative area of the anode and cathode has a pronounced effect upon the amount of corrosion that occurs. A small anode (the less noble metal, such as aluminium) joined to a large cathode (the more noble metal, such as stainless steel) will result in a high current density on the aluminium, and hence a high rate of corrosion. The corrosion is concentrated by the area difference. Conversely if the area of the anode is large compared to that of the cathode this dilutes the corrosive effect, in many cases to the extent that no problem occurs. It is common practice to use stainless steel fasteners to fix aluminium sheeting or signs, but if aluminium screws were used to fix stainless steel sheet the screws may rapidly corrode.

An apparent contradiction of the area effect occurs when the component comprised of the two metals is only partly wetted. Consider for instance a stainless steel bolt in an aluminium plate; if water collects in the corner at the edge of the bolt but the remainder of the plate remains dry, the effective area of the less noble aluminium is only the wetted region, which may be only a similar size to that section of the bolt that is wetted .... thus, it is quite possible for the aluminium plate to be galvanically attacked in the region immediately surrounding the bolt. Only the wet “area” counts.

Crevices & Stagnant Conditions

As shown in the electrochemical series chart on the next page there are two different potentials associated with each stainless steel grade. The less noble value shown in outlined boxes is that which applies inside a crevice formed between the two dissimilar metals or such as beneath bio-fouling. Such a crevice could be from the design or fabrication of the component, and formation of biological films is more likely in stagnant or slow-flowing sea water. The result of these stagnant conditions is oxygen depletion and the less noble potential which can make the stainless steel susceptible to corrosion in conditions that might otherwise be considered non-corrosive.

Passive Surface Films

Stainless steels naturally form passive surface films – this is what makes them “stainless”. This film also reduces the amount of current available for corrosion, so slows the corrosion rate down compared to some other galvanic pairs.

Avoidance of Galvanic Corrosion

The methods for avoidance of galvanic corrosion are in general suggested by the above descriptions of the conditions necessary for its occurrence.

Don’t Mix Metals. If only one material is used in a construction the problem is avoided (Condition 1 is not present – no mixed metals). Be particularly aware of zinc plated or galvanised fasteners in stainless steel sheets – a common substitution because of perceived cost savings, better availability or just incorrect material identification. These less noble fasteners look fine when installed but are likely to be rapidly attacked.

Prevent Electrical Contact. It is often practical to prevent electrical contact between the dissimilar metals (removal of Condition 2). This may be achieved using non-conducting (e.g. rubber or plastic) spacers, spool pieces or gaskets, perhaps in conjunction with sleeves around bolts. For the same reason a gap may be left between galvanised roofing and a stainless steel down-pipe.

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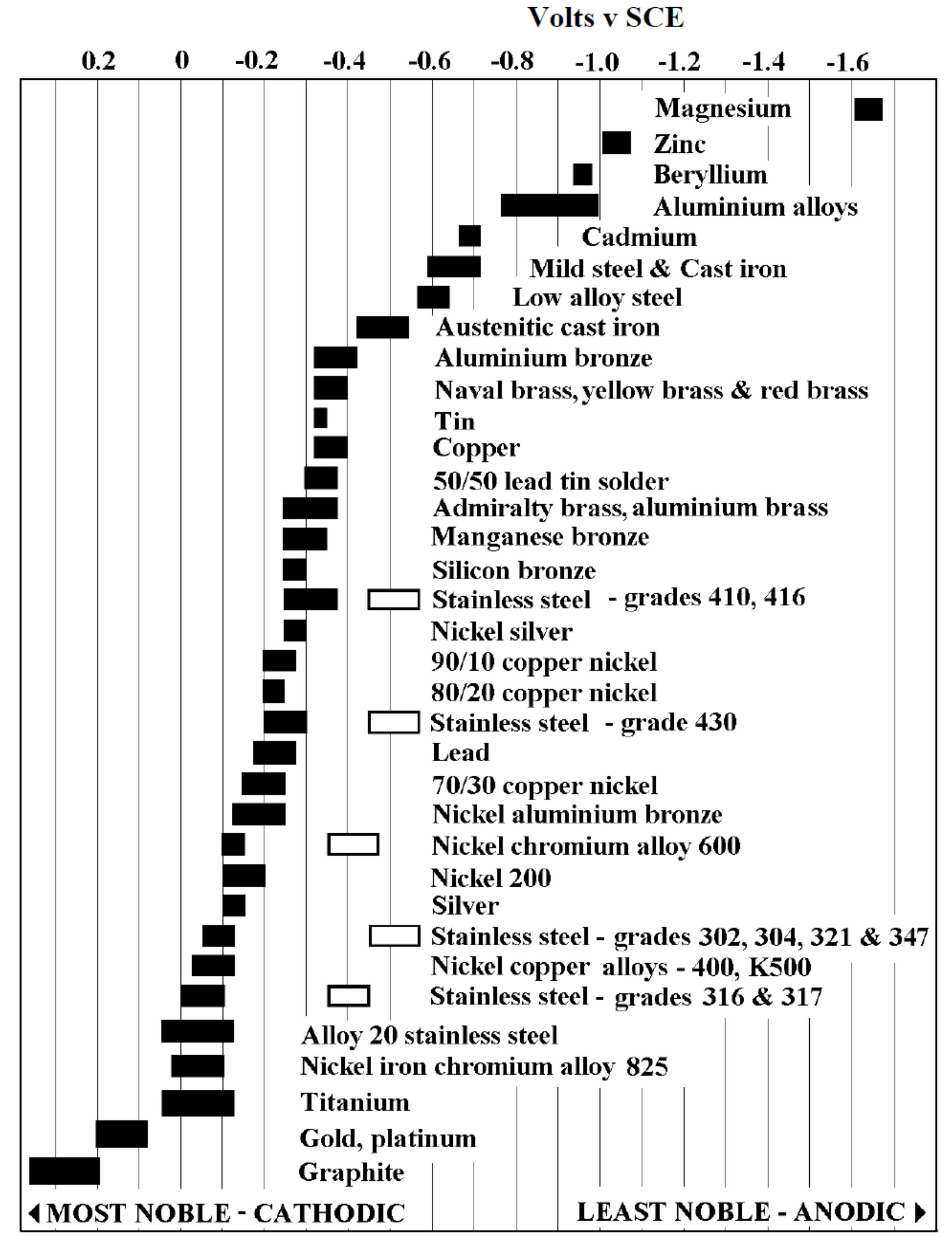
Atlas Tech Note No. 7
Galvanic Corrosion



Corrosion potentials in flowing sea water at ambient temperature. The unshaded symbols show ranges exhibited by stainless steels in acidic water such as may exist in crevices or in stagnant or low velocity or poorly aerated water. The more Noble materials at the left side tend to be cathodic and hence protected; those at the right are less Noble and tend to be anodic and hence corroded in a galvanic couple.

Atlas Tech Note No. 7
Galvanic Corrosion

Prevent the Wetted Junction. The third Condition can be removed by ensuring that no electrolyte remains at the intermetallic junction - this may require extra attention to drainage or to protection from the weather. A good covering of paint or sealant over the junction can be effective.

Use the Area Effect. The area effect should also be considered in avoiding corrosion damage, particularly in selection of fastener materials. Stainless steel fasteners can be used to hold aluminium structures, but the area effect will not apply if the wetted area shrinks over time due to evaporation.

Positively Use Galvanic Protection. A positive application of galvanic protection is the common use of active metal anodes such as aluminium or zinc (or alloys) to protect carbon steel hulls or 316 propellor shafts on seagoing boats or magnesium anodes in fresh water to protect coated steel hot water tanks.

References for Further Reading

1. Atlas Tech Note 2, "Pitting and Crevice Corrosion of Stainless Steels".
2. Sedriks, A.J., "Corrosion of Stainless Steels", Wiley Interscience, 2nd Edition, 1996.
3. ASM Specialty Handbook "Stainless Steels", ASM International, 1994.
4. AS 4036-2006 “Corrosion of metals – dissimilar metals in contact with seawater”
5. ASSDA Technical FAQ No1 “Galvanic / dissimilar metal corrosion”
6. AS HB39-1997 “Installation code for metal roof and wall cladding”